

An Absolute Method of Measuring Standing Wave Ratio and Aerial Impedance

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IN recent years there have been many descriptions of devices for measuring the impedance presented to a transmitter by an aerial and feeder system, but virtually all have been based on the r.f. bridge. For most of these devices it has been claimed that they measure standing wave ratio (s.w.r.), but in fact, they only perform this function correctly when the feeder in use has precisely the same impedance, Z_0 , for which the bridge is designed, and when the feeder is connected to the bridge in an ideal manner, i.e., without stray inductance or capacitance.

These ideal conditions are very seldom attained in amateur equipment and, while useful relative readings are usually obtained, there is often cause to doubt the absolute values of s.w.r.

The method favoured by G3DQU for h.f. use is simple, if a little laborious, and is possibly the only truly absolute method of measuring s.w.r. as in principle it amounts to cutting the feeder at various points and inserting an ammeter to measure the current. It can be used as an alternative to the bridge method, or simply as a check on the accuracy of bridge measurements. But by an extension of the process and the introduction of a little mathematics, it can also be used to measure the resistive and reactive components of the impedance presented to the feeder by the aerial and its matching system.

It is thus perhaps the most satisfactory method of deciding how an aerial system should be modified to bring it into resonance and present the correct value of purely resistive load to the feeder.

The only equipment needed, in addition to that usually found in any amateur station, are two lengths of feeder of the same variety and characteristic impedance, Z_0 , as the feeder to be investigated, and some graph paper.

One of the lengths of feeder should be $\frac{1}{2}$ wavelength long, electrically, and the other should have an electrical length of one quarter wavelength. Each should be fitted with a plug at one end and a socket at the other, both of the correct impedance. The physical lengths can be found by multiplying the theoretical electrical lengths by the velocity factor of the feeder, which is usually provided in the manufacturer's literature; for coaxial cables with solid polythene insulation between inner and outer conductors the factor is usually about 0.65.

To measure s.w.r. proceed as follows: If not already fitted, an r.f. ammeter should be connected in series with the output socket of the transmitter or aerial tuning unit. This ammeter should be connected to the socket by a short length of wire and must not be disturbed during the series of measurements.

The feeder and aerial system should now be fed in the usual way by the transmitter, taking care to resonate the p.a. tank circuit and the aerial tuning unit accurately, although, if possible, with the p.a. loaded to slightly less than its normal maximum input. Make a note of the p.a. anode current and the feeder current.

The $\frac{1}{2}$ wavelength feeder section should now be inserted in series with the main feeder, and readings again taken of the p.a. and feeder ammeters. If possible, the p.a. should be loaded to the same input as before, but not by

tuning the p.a. tank or aerial tuning unit away from resonance. This process should be repeated with the $\frac{1}{4}$ wavelength section inserted instead of the $\frac{1}{2}$ wavelength section, and finally with both the $\frac{1}{2}$ wavelength and $\frac{1}{4}$ wavelength sections incorporated.

If it has not been possible to load the p.a. to the same input for each of the readings, the feeder ammeter readings should be corrected to values related to a common power input level, e.g., if the feeder ammeter reads 0.6A with 30 watts input to the p.a. with one feeder length, and 0.2A with 15 watts input on another feeder length, the second feeder current reading should be corrected to the 30 watts input level by multiplying by the square root of the input ratio:

$$0.2 \times \sqrt{\frac{30}{15}} = 0.283A.$$

Plotting the Measurements

We now have four readings of feeder current taken at $\frac{1}{8}$ wavelength intervals and these should be plotted on graph paper as shown in Fig. 1.

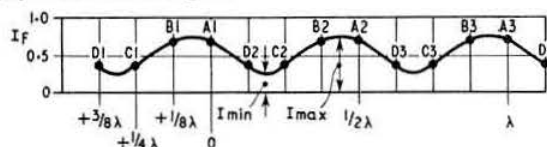


Fig. 1

The actual readings, corrected if necessary, are shown at points A1, B1, C1 and D1, and to clarify the graph of the standing wave they may be repeated at $\frac{1}{8}$ wavelength intervals as shown by the points A2, B2, C2, D2 and A3, B3, C3 and D3. An examination of the points plotted and a little imagination will enable the graph to be drawn as shown, where the s.w.r. is simply the ratio of the maximum to the minimum

$$\text{current, i.e., } \text{s.w.r.} = \frac{I_{\max}}{I_{\min}}.$$

In the example shown, readings A and B are each 0.7A, and readings C and D are each about 0.35A. $I_{\max}$ obviously occurs between A and B and is about 0.75A, while $I_{\min}$ occurs between C and D and is about 0.25A. The s.w.r. is

$$\text{thus } \frac{0.75}{0.25} = 3.$$

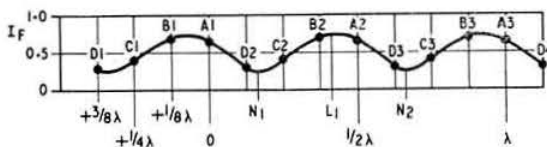


Fig. 2

Fig. 2 illustrates a different group of readings which gives the current loops and nodes further to the left, i.e., nearer to the transmitter than in Fig. 1. This is because the current at A is less than at B and that at D is less than at C. The maximum and minimum currents are, however, the same as in Fig. 1.

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When drawing these standing waves it should be remembered that the wave shape depends on the s.w.r. Fig. 3 shows how the shape varies with s.w.r.

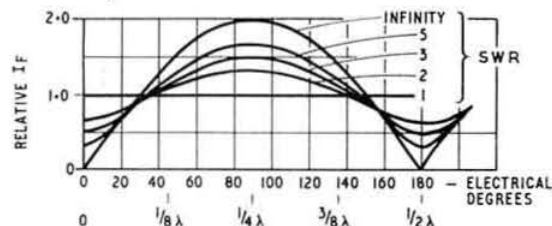


Fig. 3

Aerial Impedance

Having found the s.w.r. the average amateur will wish to reduce it by adjusting the aerial length or the matching device. The usual method is to make a change at the aerial and see if it improves or degrades the s.w.r., but it simplifies matters considerably if the impedance presented by the aerial is known, because the way in which to modify the aerial to reduce the s.w.r. will then be obvious.

The s.w.r. of 3 in Fig. 2 could be due to an infinite series of aerial impedances, but if the electrical length of the feeder is known the aerial impedance can be calculated, e.g., if the feeder length is N_1 or N_2 , such that a current node occurs at the aerial, the aerial impedance will be a pure resistance equal to Z_0 multiplied by the s.w.r., whereas if the length is L_1 , i.e., ending at a current loop, the aerial impedance will be a pure reactance equal to Z_0 divided by the s.w.r. On the other hand, if the length is between N_1 and L_1 the aerial impedance is a combination of resistance and inductive reactance while the load for lengths between L_1 and N_2 is resistance and capacitive reactance.

To find this aerial impedance the first step is to determine the effective electrical length of the feeder. This could be obtained approximately by measuring the physical length and dividing by the velocity factor, but the accuracy of this method depends on the velocity factor which is seldom known sufficiently accurately for this purpose. A method which reveals the true electrical length in terms of wavelength at the desired frequency is to open-circuit the feeder at the aerial, preferably disconnecting it entirely. Then, using low power r.f. inputs, measure the feeder input currents at the $\frac{1}{4}$ wavelength points by plugging in the test sections as previously described. When these values are plotted a curve of high s.w.r. will result, similar to that of Fig. 4.

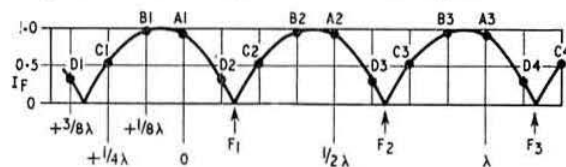


Fig. 4

Obviously, the current at the end of the open circuited feeder must be zero, so that the feeder length must be F_1 , F_2 or F_3 etc., but for the present discussion it will not matter which of these lengths is assumed to be correct. If, however, the calculated electrical length is compared with the length indicated by the standing wave graph the velocity factor can be checked and, if necessary, corrections made to the lengths of the $\frac{1}{4}$ wavelength and $\frac{1}{2}$ wavelength test sections, either by physically changing the lengths or by correcting the positions at which the points are plotted on the graph paper.

Referring again to Fig. 4, we can assume our feeder length to be from the zero point to F_1 , i.e., equal to $\frac{1}{4}$ wavelength (60°).

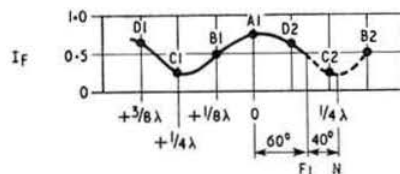


Fig. 5

To find the impedance at F_1 we need to estimate the s.w.r. and the distance in electrical degrees between F_1 and the nearest current node or loop to the right. Fig. 5 shows a typical example in which the node N is 40° to the right of F_1 . The load at N would be a fictitious pure resistance R_N equal to $Z_0 \times \text{s.w.r.}$, and the distance between F_1 and N indicates an imaginary additional length of feeder which would be present if the feeder load was R_N . The actual load at the aerial end of the feeder Z_F can be calculated from the formula $Z_F = Z_0 \frac{R_N + jZ_0 \tan 40}{Z_0 + jR_N \tan 40}$ where $\tan 40$ is the tangent of the electrical angle of distance between F_1 and N .

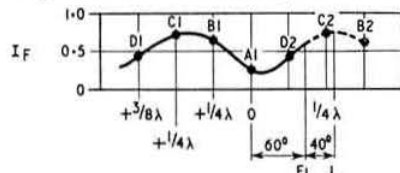


Fig. 6

A similar example is given in Fig. 6 but in this case the nearest point for a pure resistive load to the right of F_1 is the current loop L and the load at this point would be $R_L = \frac{Z_0}{\text{s.w.r.}}$. Again the load at the end of the feeder can be calculated from the formula $Z_F = Z_0 \frac{R_L + jZ_0 \tan 40}{Z_0 + jR_L \tan 40}$ where $\tan 40$ is the tangent of the distance between F_1 and L .

The method can obviously also be used to determine the impedance presented to the aerial tuning unit or transmitter, a knowledge of which is often of value in matching the transmitter to the aerial and feeder system. For those unfamiliar with, or who wish to avoid, the somewhat tedious process of solving the expression for Z_F , reference may be made to published curves (e.g., the ARRL *Antenna Book*) giving feeder input resistance and reactance values (in terms of Z_0) for various values of s.w.r. and feeder electrical lengths from resistive loads.

Conclusions
Throughout this article it has been maintained that the results are absolute, and this is theoretically true, but it should be remembered that results can be affected by mismatch at the plugs and sockets. Hence, it is recommended that components of known impedance and quality be used throughout.

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